MOTION DRIVE ALGORITHMNS AND SIMULATOR DESIGN TO STUDY MOTION EFFECTS ON INFANTRY SOLDIERS

Harry J. Zywiol, Jr., U.S. Army Tank-Automotive Research Development and Engineering Center (TARDEC), Warren, MI, 48397. Tel - 586-574-5032. zywiolh@tacom.army.mil

Dr. Richard Romano, Realtime Technologies Incorporated, Clawson, MI. Tel – 248-705-0705. romano@simcreator.com

ABSTRACT

Army vehicle and system developers need to mitigate potential problems of motion sickness described by Cowings, Toscano, DeRoshia, & Tauson, [1] and ensure that crewstation designs are optimized in their adaptation to the soldier. Using a motion base simulator, Engineers and Scientists at the U.S. Army Tank-Automotive Research, Development, and Engineering Center, TARDEC, have begun a program to study motion effects on soldiers who are transported in infantry carriers in extended road marches.

Several experiments are being designed and configured on the TARDEC National Automotive Center (NAC) Ride Motion Simulator (RMS) that recreate the proving ground environment in the laboratory to permit further study of motion sickness symptoms, their affects on soldier performance, and eventually mitigation techniques. The RMS is capable of high-transient motion dynamics to give the occupant very realistic mobility cues. This paper describes the motion drive algorithm and simulator configuration for the first of these soldier studies. Motion data was recorded on a combat vehicle at a US Army proving ground. These data were transformed and preprocessed using a motion drive algorithm into motion drive data for the 6 DOF simulator. By preprocessing the motion data with a non stationary linear quadratic optimal motion drive algorithm it was found that substantial specific forces cues could be recovered using tilt coordination and linear motion of the base.

INTRODUCTION

The U.S. Army's Future Combat System (FCS) program [2] will develop network centric concepts for a multi-mission combat system that will be overwhelmingly lethal, strategically deployable, self-sustaining and highly survivable in combat through the use of an ensemble of manned and unmanned ground and air platforms. The goal of the FCS program is to design such an ensemble that strikes an optimum balance between critical performance factors, including ground platform strategic, operational and tactical mobility; lethality; survivability; and sustainability. This system of systems design will be accomplished by using modeling, simulation and experimentation. The FCS unit will be capable of adjusting to a changing set of missions, ranging from warfighting to peacekeeping, as the deployment unfolds. An FCS-equipped force will be capable of providing mobile-networked command, control, communication and computer (C4) functionalities; autonomous robotic systems; precision direct and indirect fires; airborne and ground organic sensor platforms; and adverse-weather reconnaissance, surveillance, targeting and acquisition.

Of particular interest to the driving simulator community is that the FCS Operational Requirements Document states two requirements must be met. The first requirement states that Army operations are performed "on-the-move." The second states that these "on-the-move" operations be performed "without adverse effects." In the past, command and control operations were usually performed in a stationary vehicle. Typical operations could include surveillance, gathering intelligence information, or route planning. However, in the near future, these operations will have to be performed in a moving vehicle environment in order to maintain a swift operational tempo. The concern among human factors specialists is that adverse effects on soldiers will increase unless new vehicle crewstation designs address these command and control issues with a proven soldier/machine interface.

1. REPORT DATE **08 OCT 2003**	2. REPORT TYPE **Journal Article**	3. DATES COVERED **07-09-2003 to 07-10-2003**

4. TITLE AND SUBTITLE **MOTION DRIVE ALGORITHMNS AND SIMULATOR DESIGN TO STUDY MOTION EFFECTS ON INFANTRY SOLDIERS**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **Harry Zywiol**	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Realtime Technologies Incorporated,1523 North Main Street ,Royal Oak,Mi,48067**	8. PERFORMING ORGANIZATION REPORT NUMBER **; #13917**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **U.S. Army TARDEC, 6501 East Eleven Mile Rd, Warren, Mi, 48397-5000**	10. SPONSOR/MONITOR'S ACRONYM(S) **TARDEC**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) **#13917**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Army vehicle and system developers need to mitigate potential problems of motion sickness described by Co wings, Toscano, DeRoshia, & Tauson, [I] and ensure that crewstation designs are optimized in their adaptation to the soldier. Using a motion base simulator, Engineers and Scientists at the U.S. Army Tank-Automotive Research Development, and Engineering Center, TARDEC, have begun a program to study motion effects on soldiers who are transported in infantry carriers in extended road marches. Several experiments are being designed and configured on the TARDEC National Automotive Center (NAC) Ride Motion Simulator (RMS) that recreate the proving ground environment in the laboratory to permit further study of motion sickness symptoms, their affects on soldier performance, and eventually mitigation techniques. The RMS is capable of high-transient motion dynamics to give the occupant very realistic mobility cues. This paper describes the motion drive algorithm and simulator configuration for the first of these soldier studies. Motion data was recorded on a combat vehicle at a US Army proving ground. These data were transformed and preprocessed using a motion drive algorithm into motion drive data for the 6 DOF simulator. By preprocessing the motion data with a non stationary linear quadratic optimal motion drive algorithm it was found that substantial specific forces cues could be recovered using tilt coordination and linear motion of the base.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Public Release**	**26**	

TARDEC Ride Motion Simulator

The Ride Motion Simulator described by Nunez, Paul, and Brudnak [3], is being configured to study motion effects on infantry soldiers. A photograph of the simulator is shown in Figure 1.
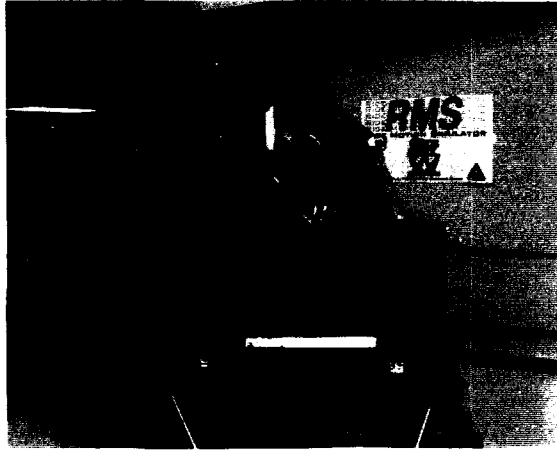

FIGURE 1 Ride Motion Simulator

The simulator features an electro-hydraulic 6 degree of freedom table on which a vehicle cab structure can be mounted. A re-configurable cab supports one occupant. The simulator can be outfit with displays driven by a real-time image generator, driving controls, and an audio generation system. Simulations can be built using paved road or cross country visual and terrain databases, coupled with multi-body vehicle dynamics models traversing these databases.

Simulator experiment designs

Currently, there are three experiment designs being set up using the Ride Motion Simulator that begin to address the FCS on the move and adverse effects requirements. These are briefly described here:

Indirect driving versus Head Mounted Display (HMD) driving. *Indirect* driving is a design where the vehicle driver views are portrayed on display screens rather than *directly* looking through windshields or vision blocks. Vehicle cameras, appropriately placed, produce an image of the outside environment that is displayed on a screen for the vehicle driver. Indirect vision systems can result in a vehicle designs that are safer for the crew since a direct line of sight for the driver is not required. Head mounted displays, for driving purposes, carry the indirect display one step further in that the driver is more immersed in the scene. Data can be displayed within the scene as well as providing the driver with additional navigation or other information. A head or eye tracker can render the scene per the direction of this head or eyes.

Indirect driving in a tele-operations mode. Army researchers are exploring the ground vehicle simulation design for use in robotic applications and other tasks. Tele-operating an unmanned ground vehicle (UGV) when both control and robotic vehicle are in motion presents a number of challenges for the control operator. This is because the operator is continuously experiencing different and therefore conflicting visual and motion cues. The tele-operation task coupled with command and control tasks could present situations too difficult for the soldier to handle.

Effects on infantry soldiers in a road march environment. Typically, a squad of about nine soldiers will be confined in the rear of an infantry carrier during a road march of several hours. The soldiers have no periscopes or view of the outside world. Soldiers have known to become disoriented and ill, especially when they are asked to conduct command and control functions. The RMS is being configured to replicate the motion and vibration road march environment so that it can be accurately presented to soldiers in a laboratory environment. Studies will be

performed to measure how well each soldier performs various infantry tasks as they exit (dismount) from the simulator.

SIMULATOR CONFIGURATION AND DATA PROCESSING

Proving ground data collection

TARDEC recently seized an opportunity to obtain some data that was collected at the U.S. Army Proving Ground in Aberdeen Maryland. The goal of the data collection was to validate the RMS as a tool for human performance testing. The data were recorded off a new, eight-wheeled, combat vehicle called the Stryker, shown in Figure 2.

FIGURE 2 Stryker vehicle

The Stryker family of medium weight armored vehicles is intended to support the Interim Brigade Combat Team (IBCT) as a rapidly deployable, medium armored suite of vehicles that will provide the IBCT with mobility, lethality, and survivability in a wide variety of combat environments. The Infantry Fighting Vehicle variant of the Stryker will transport a squad of nine soldiers, with their equipment, to and around the battlefield. Once they reach their objective they will have to disembark and carry out such complex mission tasks as target acquisition, target engagement, and patrols through urban terrain settings. In short, they must be ready to perform physical (e.g., lifting, sustained load carriage), psychomotor (e.g., balance, eye-hand coordination), perceptual (e.g., accurately hearing and seeing), and cognitive (time and accuracy of responding to information) tasks. [4]

The Stryker vehicle squad was tested at the proving ground in Maryland for a number of these crew measures while traversing two courses: Perryman A and Perryman 1. These courses are characterized as secondary, gravel roads, with wide and narrow turns. They are both flat with numerous turns, although soil types differ slightly. The surface roughness of Perryman A is 8.9mm (.35 inch) rms and Perryman 1 is 10.4 mm (.41 inch) rms. The Perryman A and Perryman 1 courses are 3840 meters (2.4 miles) and 8320 meters (5.2 miles) in length respectively.

Vehicle speeds on these courses are typically 25 to 57 kph (15 to 35 mph). A number of signals were recorded from sensors mounted to the vehicle. These signals are: vehicle speed, vehicle body rate in pitch, roll, and yaw, vehicle linear acceleration in lateral, longitudinal, and vertical. Channels measuring audio and sound pressure level were also recorded from within the vehicle. The signals were digitally sampled at 500 samples per second at the proving ground and are described in Table 1.

TABLE 1 Proving ground data description

Channel number	Description	Low Pass freq. (hz)	Units
1	(V) Seat bottom accel	100	G's
2	(T) Seat bottom accel	100	G's
3	(L) Seat bottom accel	100	G's
4	Road Speed	100	mph
5	Yaw rate – motion pak	100	Deg/sec
6	Roll rate – motion pak	100	Deg/sec
7	Pitch rate – motion pak	100	Deg/sec
8	(T) motion pak accel	100	G's
9	(L) motion pak accel	100	G's
10	(V) motion pak accel	100	G's

It is desired to determine how well the RMS can replicate the one-hour road march motion environment as experienced at the proving ground. The RMS cab will be configured similarly as the interior of the Stryker carrier. See Figure 3. A bench-type seat with seat back and lap belt will be installed. Because the RMS cab is not large enough to install an entire squad cab, the video screens inside the RMS cab will display still photographs of the interior of the Stryker. A canvas shroud will be placed such that the soldier will not be able to see the outside laboratory environment. The RMS motion controller has been tuned to deliver high bandwidth motion drives in excess of 25 hertz.
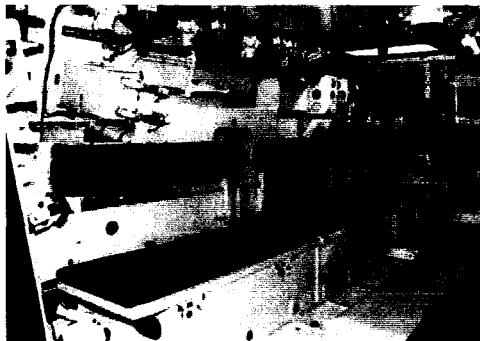
FIGURE 3 Interior view of Stryker vehicle compartment

4

Experiment plan.

An experiment using the Ride Motion Simulator is being considered. It will replicate some of the Proving Ground conditions in an attempt to validate using the simulator for future vehicle on-the-move efforts. Twelve rifle-qualified infantry soldiers will be tested in the simulator. Each soldier will be subjected to the following:

- 1 hour road march in motion simulator

- dismount from simulator

- walk on narrow wooden rails. The soldiers' balance ability will be recorded.

- rifle shooting using indoor firing simulator. The soldiers' firing performance will be recorded.

- motion sickness and cognitive questionnaires will be administered

PREPROCESSING THE DATA FOR THE SIMULATOR

Washout algorithms are used in driving simulators to translate the large motions of the actual vehicle into the limited motion envelope of the motion base. Typically, tilt coordination is used in the washout algorithms to represent steady state specific forces by rotating the motion base to align gravity with the total specific force vector of the simulated vehicle. A new tilt coordination control method was developed by Romano [5] for use with motion washout algorithms. Starting with the classical washout algorithm, the typical linear high-pass filters were removed from the algorithm and a linear model of the tilt coordination circuit was developed. A linear quadratic Gaussian regulator (LQGR) was developed that controls the tilt channel to minimize both commanded tilt rate and total motion base position.
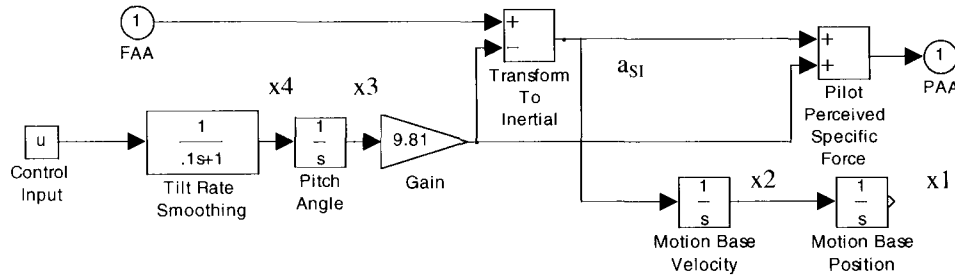
FIGURE 4 Linearized Algorithm

The new algorithm is shown in Figure 4. The control input u is tilt rate. The control input u is first smoothed using a first order lag and then integrated to yield a pitch angle. Tilt rate was selected as the control input u so that the maximum tilt rate can be controlled. If the output from the tilt rate smoothing is defined as the state x4, the integration of the pitch angle defined as x3, the velocity of the platform defined as x2, and the position is defined as x1, the algorithm can be represented using its equivalent state space representation.

$$\frac{d}{dt}\begin{bmatrix} x1 \\ x2 \\ x3 \\ x4 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & -9.81 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & -\frac{1}{c} \end{bmatrix}\begin{bmatrix} x1 \\ x2 \\ x3 \\ x4 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{1}{c} \end{bmatrix}u \tag{1}$$

A linear quadratic Gaussian regulator (LQGR) was selected to calculate the control input u. To find an optimal solution the specific force input f_{AA} was treated as white noise system disturbance filtered through a first order lag

5

with a time constant of 0.05 seconds. While modeling the specific force as white noise is not exact, it makes the problem tractable. The state equation of the external input becomes:

$$\frac{d}{dt}[f_{AA}] = [-1/0.05][f_{AA}] + [0]u + w \tag{2}$$

where w is white noise. Kwakernaak [6] presented an approach to solve this type of problem. The original state equations in Equation 1 and the state equation in Equation 2 are combined to yield the augmented system given in Equation 3.

$$\frac{d}{dt}\begin{bmatrix} x1 \\ x2 \\ x3 \\ x4 \\ x5 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & -9.81 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -\dfrac{1}{c} & 0 \\ 0 & 0 & 0 & 0 & -20 \end{bmatrix}\begin{bmatrix} x1 \\ x2 \\ x3 \\ x4 \\ x5 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \dfrac{1}{c} \\ 0 \end{bmatrix}u + w \tag{3}$$

It is desirable to configure the linear quadratic regulator to control a tracking problem where the position state x1 is kept as close to zero as possible, the specific force state x5 is kept as close to the desired specific force as possible and the control input u is minimized. A second control input is introduced to allow control of the specific force input f_{AA}.

$$\frac{d}{dt}\begin{bmatrix} x1 \\ x2 \\ x3 \\ x4 \\ x5 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & -9.81 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -\dfrac{1}{c} & 0 \\ 0 & 0 & 0 & 0 & -20 \end{bmatrix}\begin{bmatrix} x1 \\ x2 \\ x3 \\ x4 \\ x5 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \dfrac{1}{c} & 0 \\ 0 & 20 \end{bmatrix}u \tag{4}$$

This is accomplished with the following cost function:

$$J = E\left[\int[z-r]^T Q[z-r] + u^T Ru\, dt\right] \tag{5}$$

where $E[\,]$ indicates the expected value, Q, R are weighting matrices, r is the desired command to track and:

$$\begin{bmatrix} z1 \\ z2 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} x1 \\ x2 \\ x3 \\ x4 \\ x5 \end{bmatrix} \tag{6}$$

The optimal solution to the linear tracking problem is [6]:

$$u^* = -R^{-1}B^T Ux - R^{-1}B^T s \tag{7}$$

6

where U is the positive, semi-definite, symmetric solution to the Riccati equation:

$$\dot{U} = -UA - A^T U - D^T QD + UBR^{-1}B^T U \tag{8}$$

and s is the solution of the co-state equations:

$$\dot{s} = -[A^T - UBR^{-1}B^T]s + D^T Qr \tag{9}$$

Finally:

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & -9.81 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -\dfrac{1}{c} & 0 \\ 0 & 0 & 0 & 0 & -20 \end{bmatrix} \tag{10}$$

$$B = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \dfrac{1}{c} & 0 \\ 0 & 20 \end{bmatrix} \tag{11}$$

$$D = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{12}$$

After some tuning Q and R were selected as:

$$Q = \begin{bmatrix} 0.005 & 0 \\ 0 & 1 \end{bmatrix} \tag{13}$$

$$R = \begin{bmatrix} 1 & 0 \\ 0 & 4 \end{bmatrix} \tag{14}$$

To solve the optimal control U and s were integrated from the end time back to the start time using Equations 8 and 9 and initial conditions:

$$U(t_f) = H \tag{15}$$

$$s(t_f) = -D^T Hr \tag{16}$$

7

where:

$$H = \begin{bmatrix} 0.01 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2 \end{bmatrix}$$ (17)

With U and s known, Equation 4 can be integrated forward to solve for the motion base position acceleration and pitch angle.

The algorithm was tested with a data set collected on the Aberdeen proving grounds. Figure 5 shows the results of the washout algorithm compared with the real data. The blue graph is the response and the green graph is the original signal. From Figure 5 one can see that the two signals overlay each other closely.
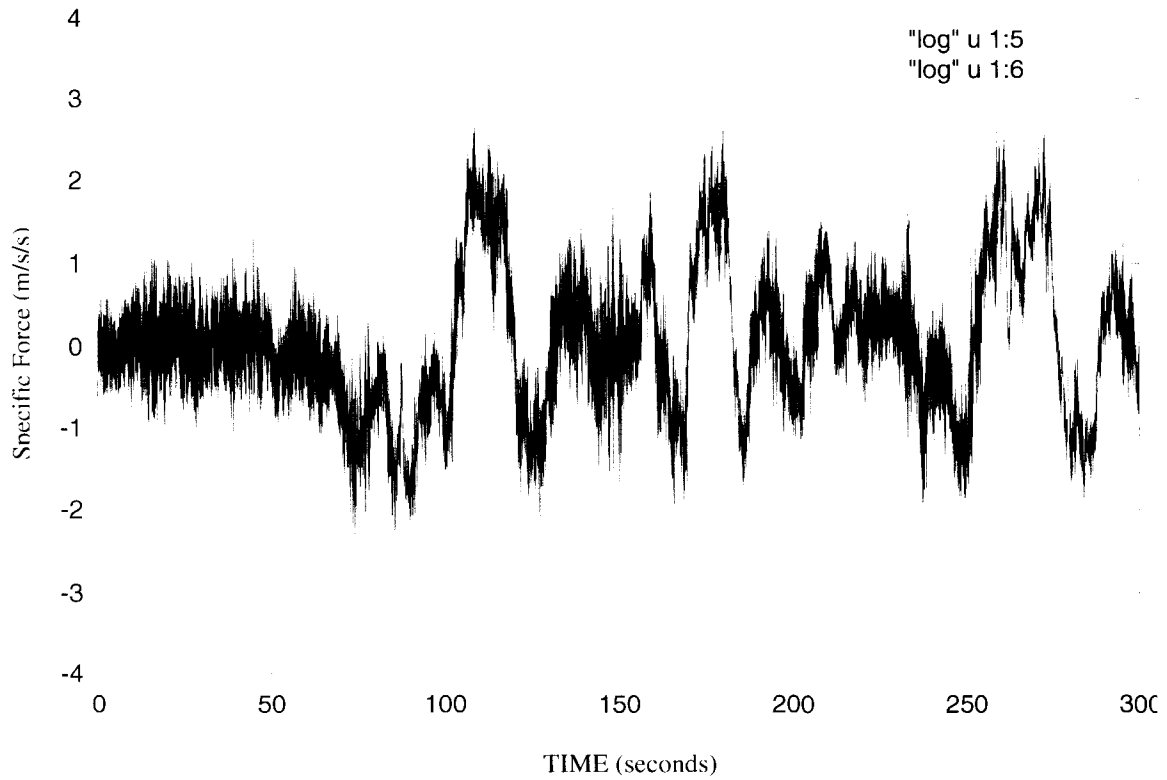
FIGURE 5 Specific Force Response of Algorithm

Figure 6 shows the same response zoomed in for the time from 25 to 26 seconds. Looking at the zoomed response there is a slight reduction in the total cue provided by the algorithm. This is because the cost function in Equation 5 will allow some reduction in the response as part of its total error calculation. Figure 7 shows the total tilt rate used by the algorithm. It can be seen that the tilt rate is maintained at less than 4 degrees/second (0.7 radians/second) for almost all the run and the tilt rate is typically well below 3 degrees/second. Finally Figure 8 shows the motion base position used by the algorithm. For most of the algorithm the total motion base is kept below 0.3 meters which is well within the available limits of TACOM's RMS simulator.

8

1.5   "log" u 1:5
                                                                                     "log" u 1:6

1

Specific Force (m/s/s)

0.5

0

-0.5

-1

-1.5
   25   25.2   25.4   25.6   25.8   26

                        TIME (seconds)
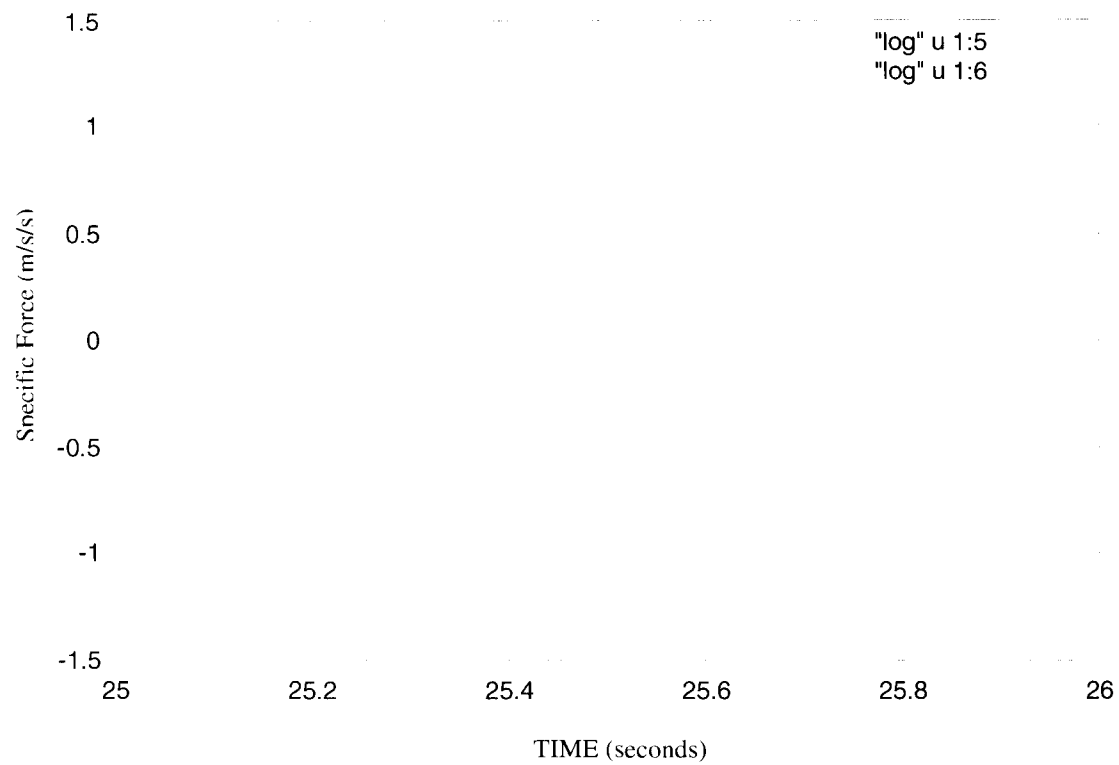
FIGURE 6 Zoom In of Specific Force Response of the Algorithm

0.06   "log" u 1:3

0.04

0.02

Tilt Rate (radians/second)

0

-0.02

-0.04

-0.06

-0.08
   0   50   100   150   200   250   30(

                        TIME (seconds)
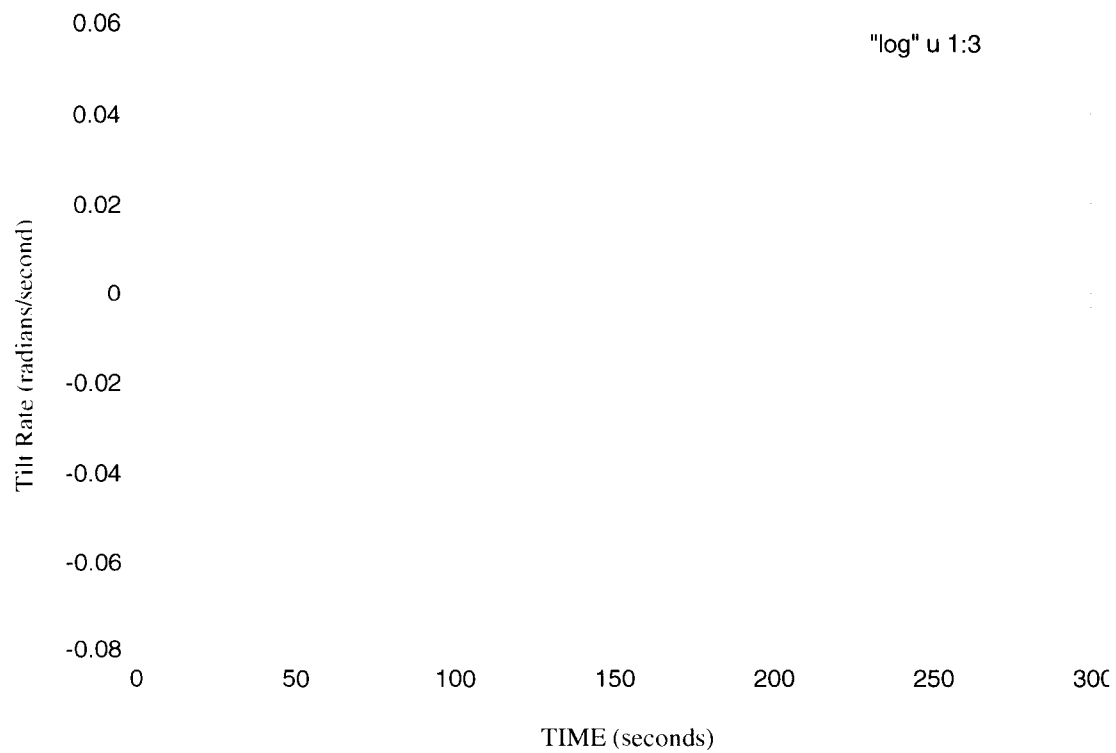
FIGURE 7 Tilt Rate Response of the New Algorithm

9
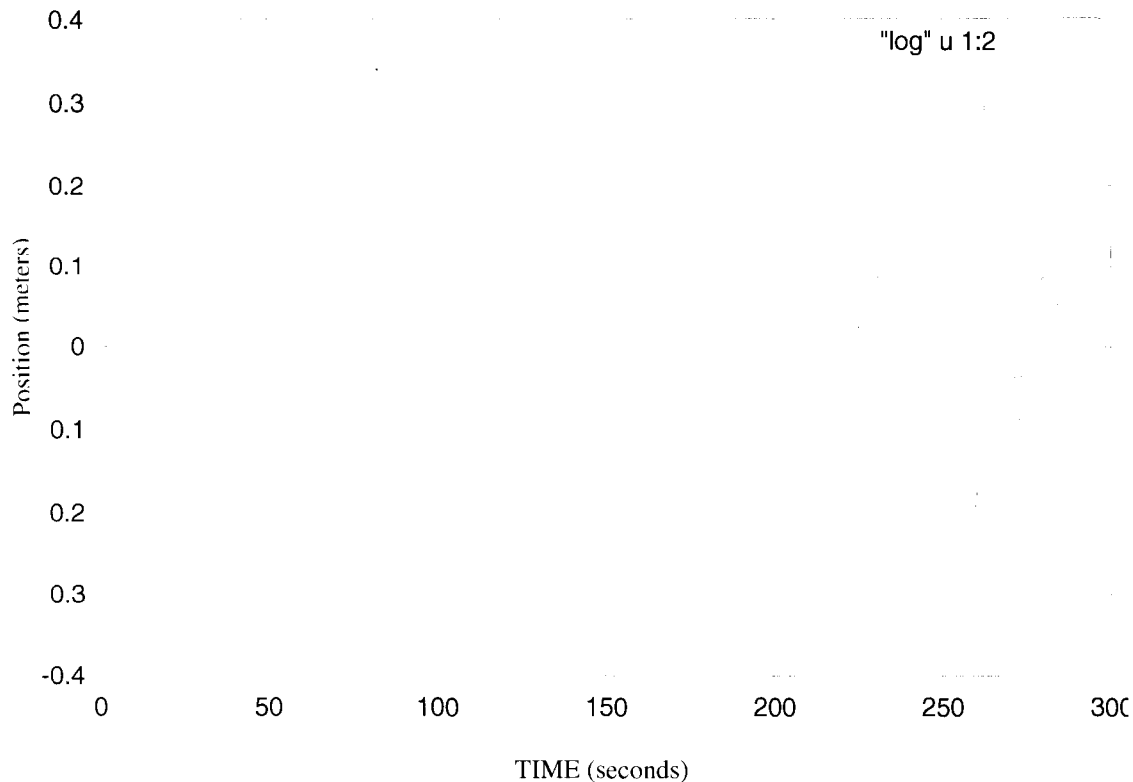
FIGURE 8 Position Response of the New Algorithm

CONCLUSION

Several experiment designs and ride simulator configurations are being considered for the study and investigation of moving vehicle operations and soldier performance. These designs will augment vehicle technology demonstrators and crewstation prototypes as these mature into production vehicles. In the future, motion sickness mitigation techniques can be tried in the simulator before more costly attempts are investigated. Caution must be exerted to decipher and determine the differences between simulator-caused sickness and motion sickness caused by poor vehicle designs.

A new motion washout algorithm was developed that converts prerecorded data into motion base position commands. Using prerecorded data an optimal set of tilt rate and acceleration commands can be developed that provides accurate specific force recovery while minimizing the total motion base envelope required.

REFERENCES

1.   Cowings P. S, Toscano, W. B., DeRoshia, C., & Tauson, R. A., "The Effects of the Command and Control Vehicle (C2V) on Soldier Health and Performance." Army Research Laboratory, 1999

2.   Web site on the Future Combat System, http://www.darpa.mil/fcs/index.html

3.   Nunez, P., Brudnak, M.J., Paul, V., "Warfighter/hardware in the Loop Simulation at TACOM-TARDEC's Ground Vehicle Simulation Laboratory (GVSL). In 1st Human Centered Transportation Simulation Conference, Iowa City, Iowa, 2001.

4.   Tauson, R. A., "An Evaluation of the Effect of Ride Quality on Squad Performance.", Army Research Laboratory, 2002

5.   Romano, R. A., "Non-Linear Optimal Tilt Coordination for Washout Algorithms", American Institute of Aeronautics and Astronautics, Modeling and Simulation Conference, Austin, Texas, 2003.

6.   Kwakernaak, H., and Sivan, R., *Linear Optimal Control Systems*, Wiley-Interscience, New York, NY, 1972.

Motion Drive Algorithms and Simulator Design To Study Motion Effects on Infantry Soldiers

for:

2003 Driver Simulator Conference
North America
October 8-10, 2003

Harry J. Zywiol, Jr., Dr. Richard Romano
US Army TACOM-TARDEC National Automotive Center
Realtime Technologies Inc.

UNITED STATES ARMY

NAC

NATIONAL AUTOMOTIVE CENTER

Briefing Outline
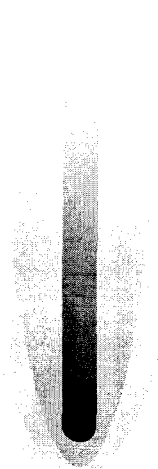
Background and Goal

Simulation Design

Motion Drive Algorithms

- Classical

- New

Response Comparisons

Conclusions
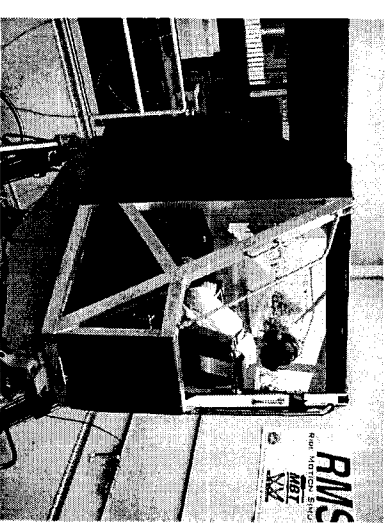
Background

-The need to study soldier/mobility issues.
-Ride Motion Simulator at TARDEC
    -6 DOF, electro-hydraulic, high performance

Current Effort

- Design a virtual motion simulation to enable
    - motion effects studies on infantry soldiers
    - Indirect driving using HMDs or flat-panels
    - Tele-operations studies
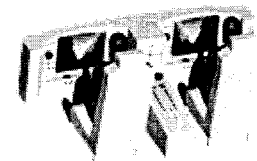
Overall Goal
Satisfy Objective Force mobility, human factors requirements
    "operate on-the-move" (tele-ops, Command and control,
    increased operational tempo)
    "function without adverse physical effects" (mitigate sickness,
    info overload)

Ride Motion Simulator Validation
Using Stryker ICV

Proving Ground Tests

Perryman Course

ICV at APG

ICV Interior

RMS Validation

RMS

Rail Walk

Shooting Simulator
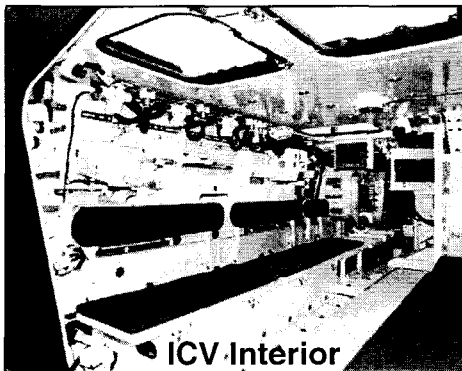
Protocol
ARL-HRED Protocol from APG Stryker Tests
Perryman 1 and A, 1 hour road march
Rifle qualified infantry soldiers

Objectives
Use APG recorded field data for RMS input
Compare APG data to RMS data
Goal – 75% correlation

Data Comparison
Vibration
Rail Walk
Shooting Simulator
Questionnaires
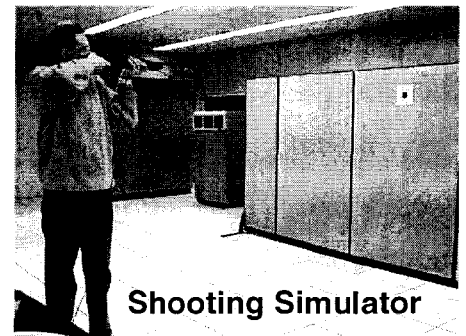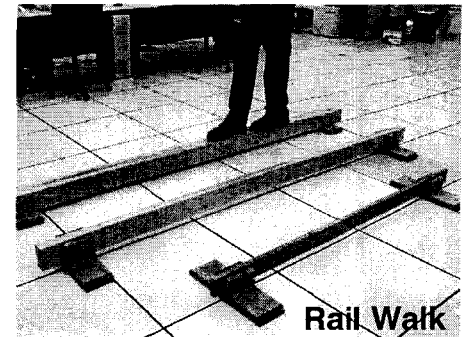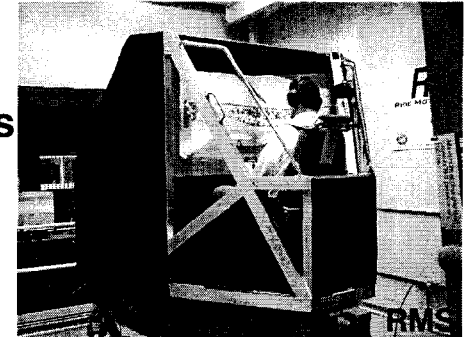
Proving Ground Data

TABLE 1 Proving ground data description

Proving Ground scenario:
-1 hour data collection
-Perryman area roads
-Speeds of 15-35 mph
-Gravel roads
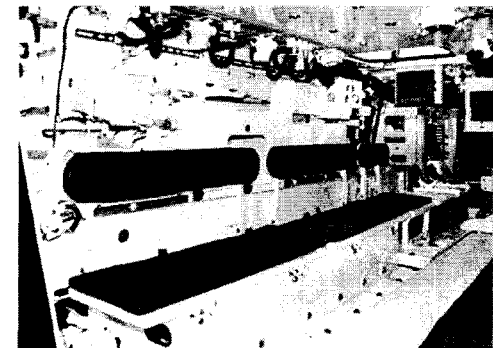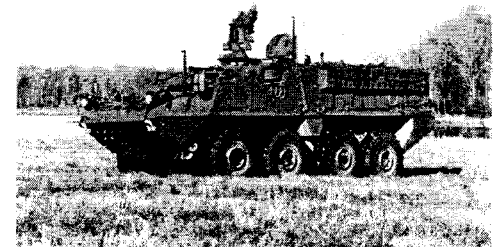
Simulator Configuration
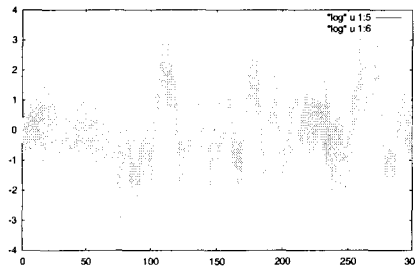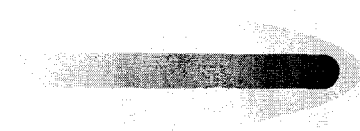
Proving Ground
Data
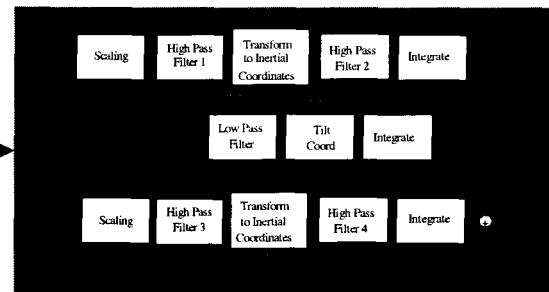
Motion Drive
Algorithm

Motion
Simulator

Classical Algorithm
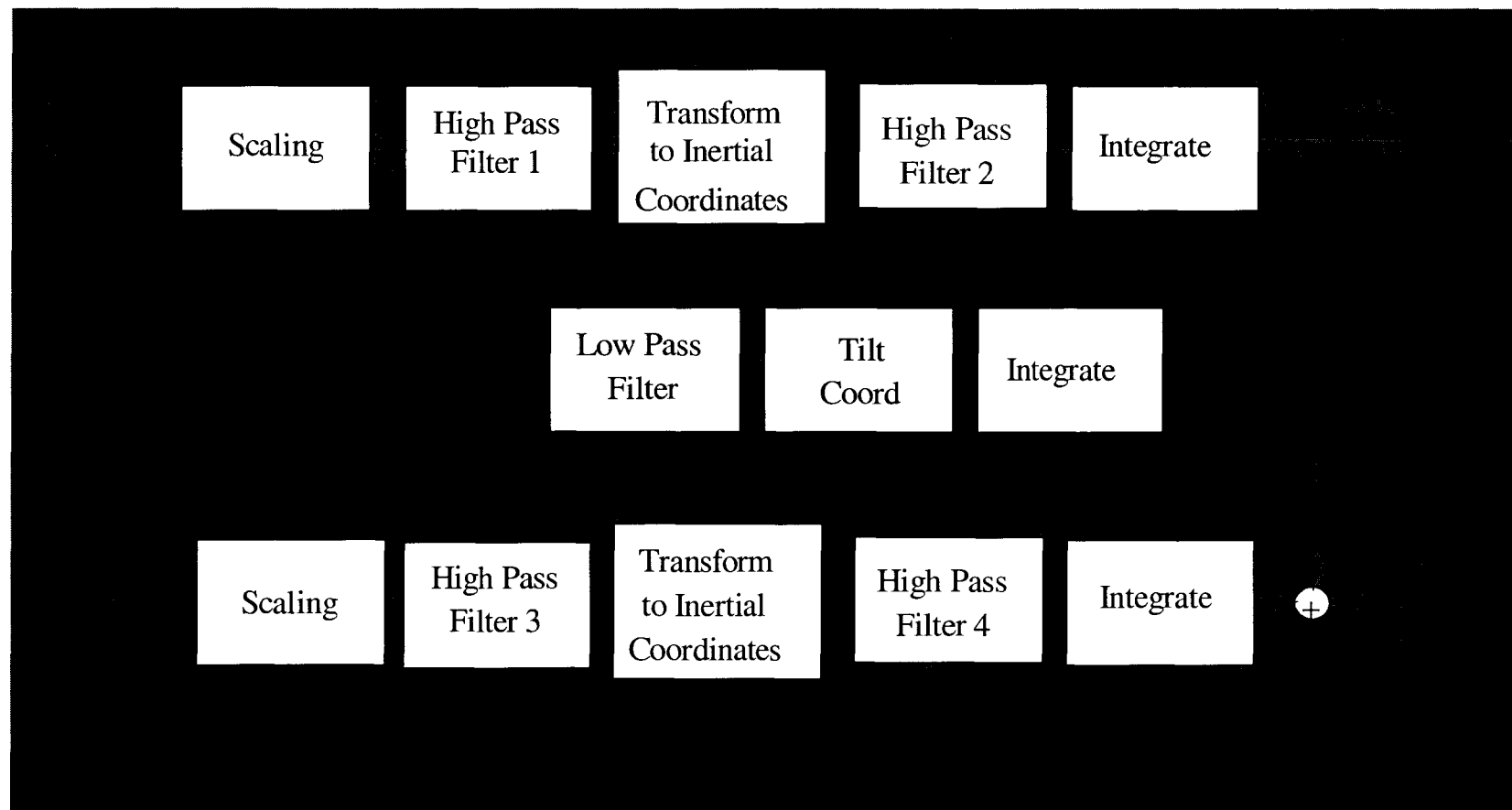
New Linearized Algorithm
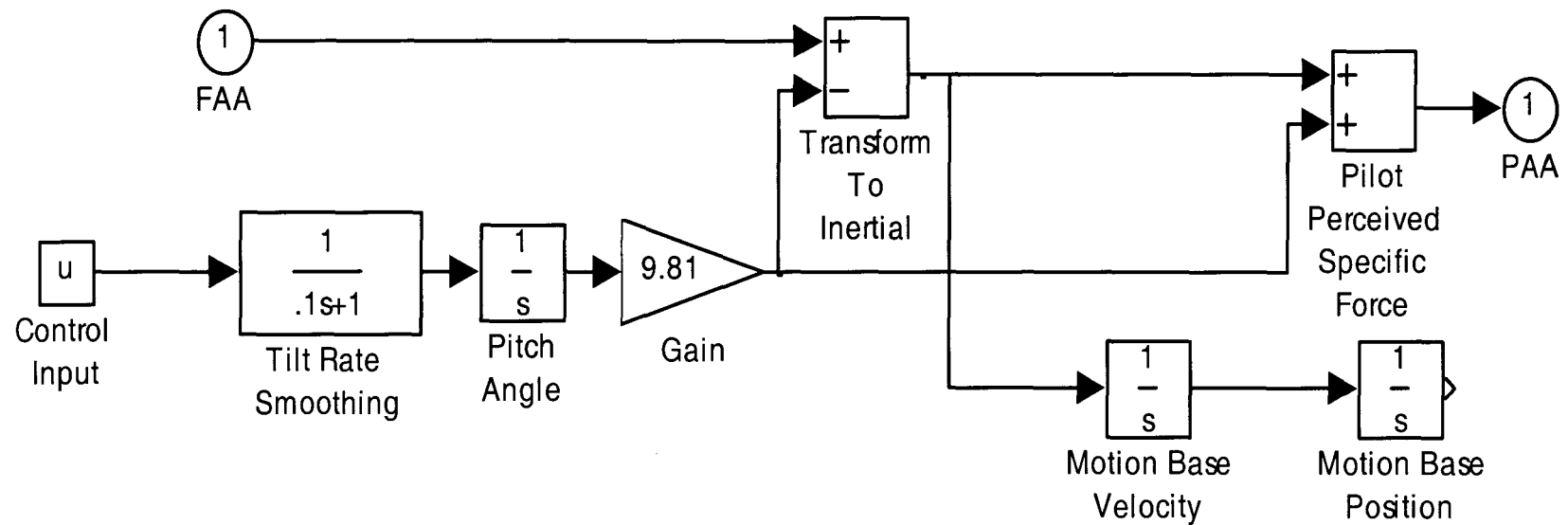
New Algorithm

•Cost function selected to minimize motion base error in specific force and commanded tilt rate.

$$J = \int \left[[z-r]^T Q[z-r] + u^T Ru \right] dt$$

$$J = \int \left[[z-r]^T Q[z-r] + u^T Ru \right] dt$$

Washout Algorithm Comparison

Compare Classical vs. New Algorithm

• Select 2 m/s**2 acceleration which is typical of the proving ground data set.
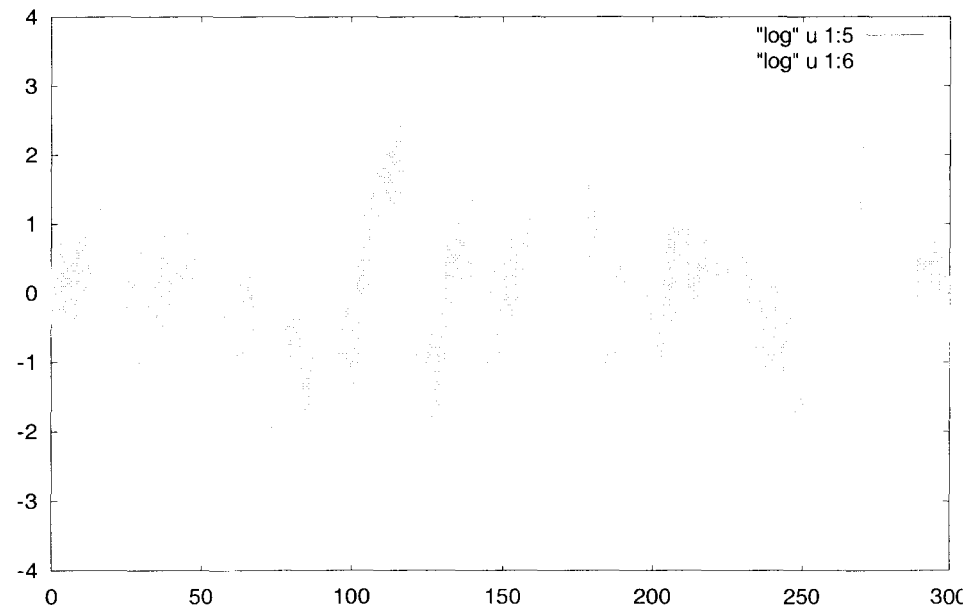
• Tune classical algorithm to have similar position and tilt rates as the new algorithm

Specific Force Comparison
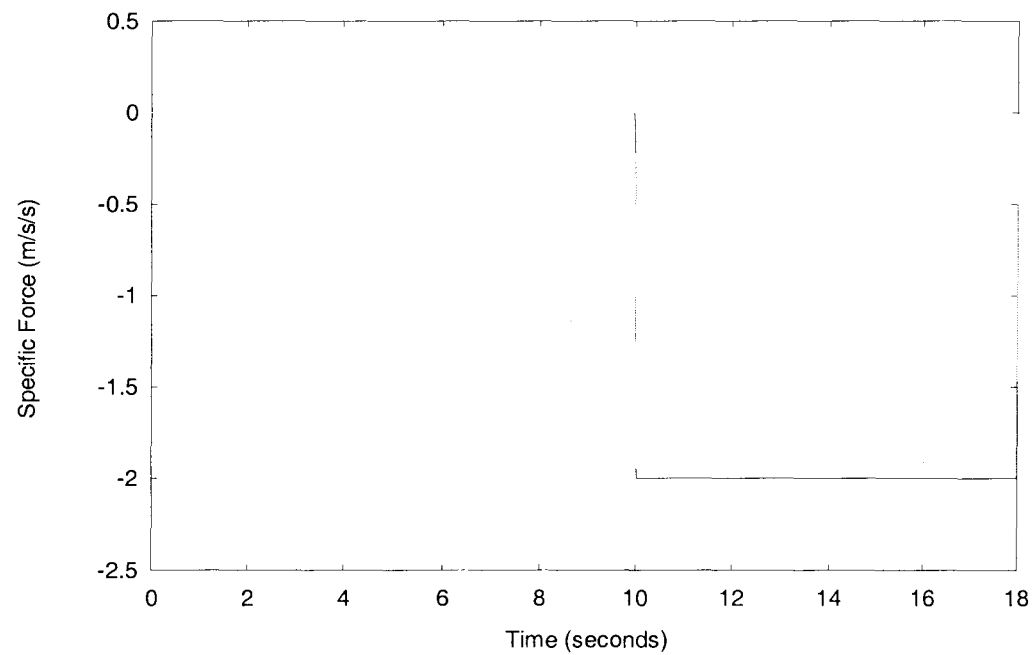
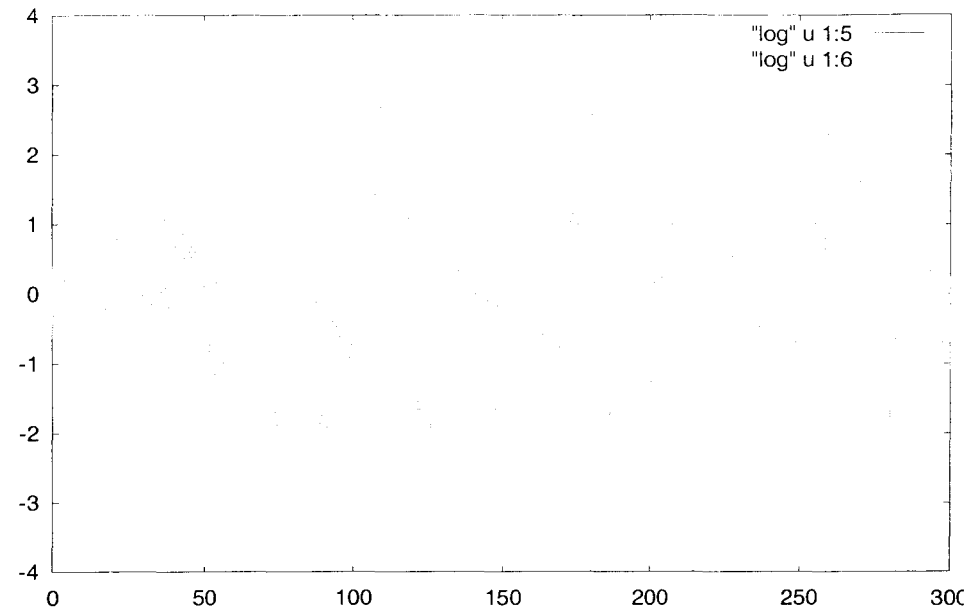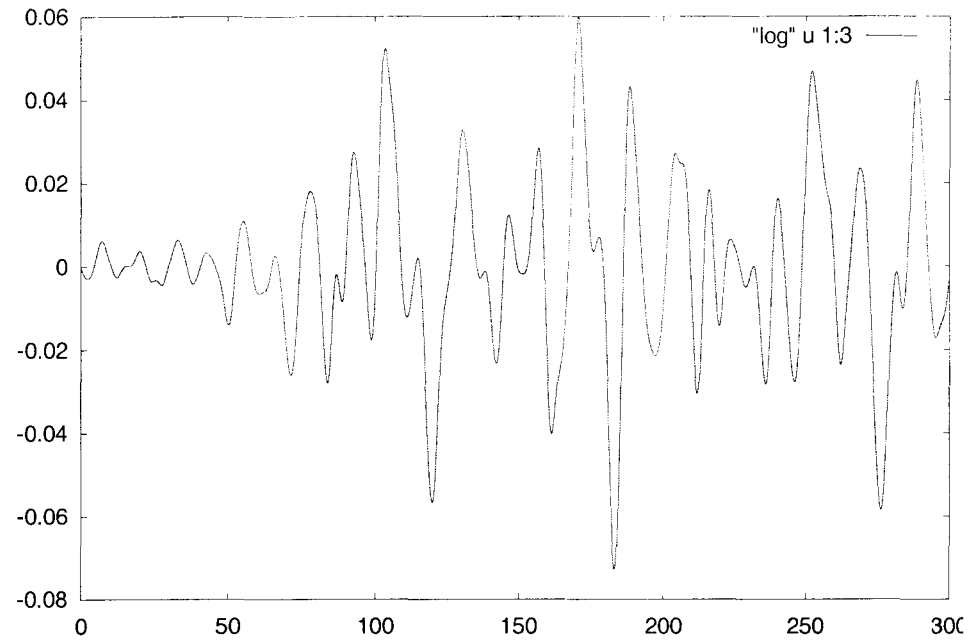# Response Comparisons

Tilt rate comparison
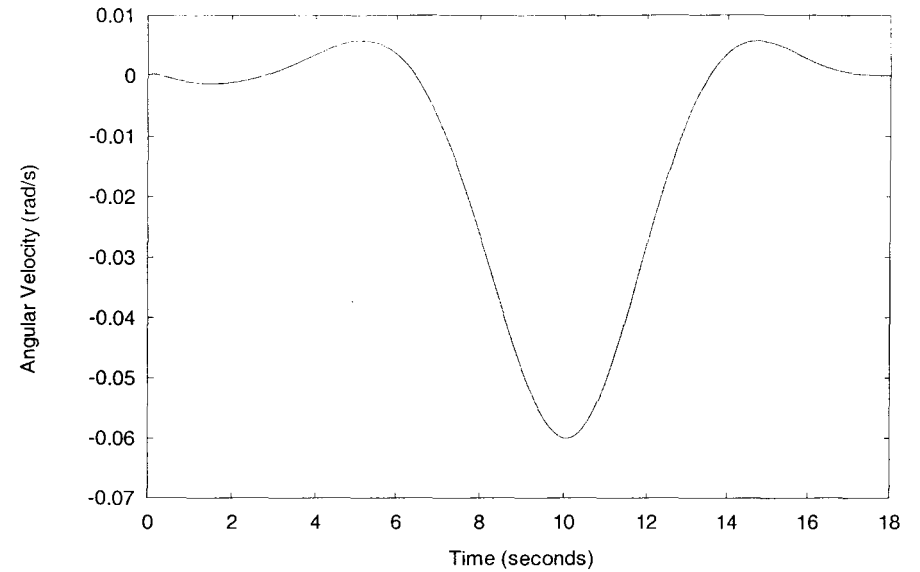
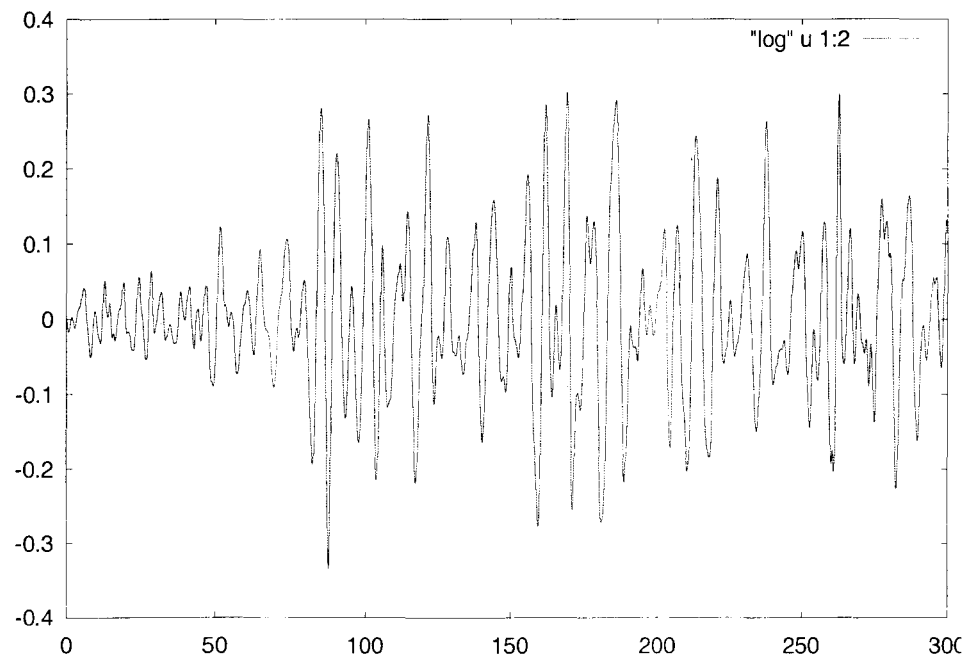Position Comparison
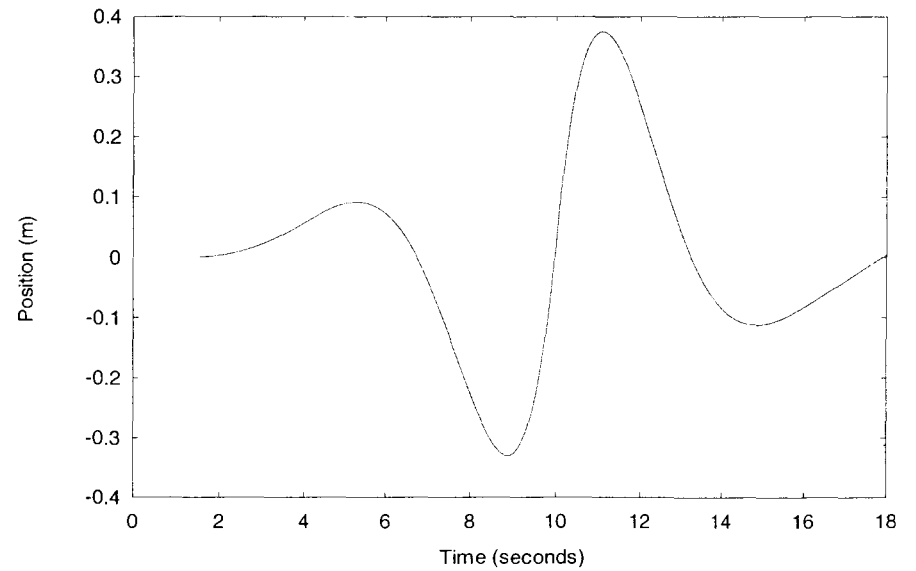
Specific Force
300 seconds of data

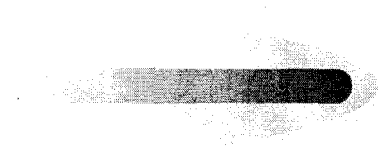Specific Force
1 second of data
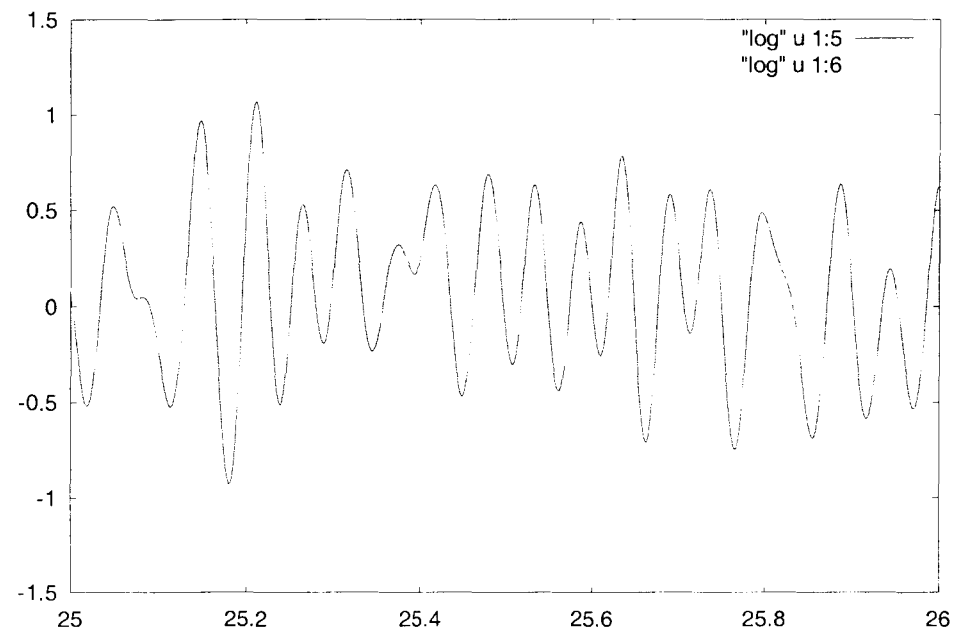
Tilt rate response
New Algorithm

Position response
New Algorithm

Conclusions

- New washout algorithm converts pre-recorded data into motion base position commands

- Produces Optimal set of tilt rate and acceleration commands

- New algorithm outperforms a typical classical washout algorithm

- Experiment designs are being considered for studying moving vehicle and soldier performance